FOUNDATION FOR CONSTRUCTIONS

BACKGROUND OF THE INVENTION

[0001] The present invention relates to a foundation for constructions, such as for example wind power installations.

[0002] Due to terrific technical development in recent years wind power installations have reached dimensions and weights which are increasingly at the limits of what is technologically feasible. The rotor of such a wind power installation has a diameter which is significantly more than 100 meters, the height of the tower can be up to 130 meters and the mass of a machine housing disposed on the tower can be up to 500 tons. The above-mentioned dimensions and weights nowadays belong to the prior art.

[0003] The tower and the foundation in particular are components in respect of which the size of the component increasingly poses a problem. Thus, for example the road transport of the towers, which are made predominantly of steel tubes, poses problems if the diameter of the tower is to be more than 4.3 meters. In general the headroom of bridges is no longer sufficient to enable a transport laden with the tower or a section of the tower to pass under a bridge.

[0004] Furthermore, the available rolling mills and welding processes limit the wall thickness and also the diameter of the machinable cylindrically rolled steel sheets. In addition the permissible transport weight of currently approximately 100 tons unit weight also limits the dimensions, so that higher unit weights also lead to substantially higher costs.

[0005] The foundation of an installation constitutes a considerable cost factor, particularly with regard to the offshore arrangement of wind power installations, i.e. wind power installations erected in the sea. Apart from the installation and maintenance costs which in any case are already much higher, this cost factor

exerts a very strong cost pressure on the offshore use of wind power, and therefore particularly in the case of the cost-intensive foundation attempts are being made to find the most economical solution possible.

[0006] The so-called monopile (single-pile) foundation which is already used singly for land-based wind power installations has hitherto been economical for average water depths. In this case, a pile located in the extension of the tower axis, usually a relatively thick-walled steel tube, is anchored in the seabed. In the case of large wind power installations, this single pile must have substantial dimensions, for example, diameters of more than 5 meters with lengths of more than 30 meters. However, the disadvantage of this known foundation is that it is already foreseeable now that in the near future it will no longer possible to produce piles which are so designed that they can bear the wind power installations which are increasingly becoming larger.

[0007] For the introduction of the monopile into the ground a ramming or pile-driving method is known as the most economical method. In the case of sandy ground, however, it is also known to use a flushing method. Furthermore, in the case of rocky underlying ground a drilling or boring method is known in which, depending upon the nature of the ground, the monopile is then cemented into the hole with a concrete-like mass (grout).

[0008] A similar cemented connection is known for the junction between monopile and tower in the offshore wind power installations. Since the upper face of the monopile is uneven, particularly in the case of the ramming method, it is not possible to use flange connections which are otherwise usual. Therefore, a junction piece, which is provided with a flange at the upper end is turned over the monopile. As a rule, this junction piece is substantially oversized relative to the monopile so that any angle error occurring during introduction of the monopile can be compensated. After alignment of the junction piece, the gap between the junction piece and the monopile is filled with a concrete-like mass (grout). In this case, the filling material serves not only for filling the cavity, but also as a joining material

(providing physical adhesion) between the components. This joining which is designated as "concrete bonding" is generally known by the term "grouted joint".

[0009] In particular, in the very economical ramming method, the dimensions of the monopile are limited both in diameter and in wall thicknesses by the rams available, which naturally have considerable dimensions. Moreover, a high weight of the monopile can lead to unacceptably high expenditure on handling and transport.

[0010] On the other hand, because of the enormous static and dynamic stresses during the 20 year service life of a wind power installation, it is generally desirable from the design point of view to produce the most stable and rigid structure possible. Moreover, the first natural frequency of the construction must often be kept within a permissible frequency window which is predetermined by the design of the wind power installation. Thus, in particular in the case of considerable water depths the frequency requirement can make it become impossible to produce a monopile with the available limiting dimensions.

[0011] Therefore, for considerable water depths the known possibilities for foundations of wind power installations include three-legged foundations (tripod) and so-called jackets (four-legged or multi-legged platforms, usually constructed as a latticework structure, the standard design in petroleum platforms). The "feet" can be anchored for example by means of gravity (concrete) and also by piles anchored in the ground. Because of the considerably higher steel consumption as well as the large number of anchoring points on the seabed which represent considerable expense, however, these foundations are much less economical than the monopile. Furthermore, the spatial extent below the surface of the water constitutes an increased risk of shipping collisions.

[0012] Furthermore, pile-like foundation elements are generally known for foundations of any kind for buildings in yielding ground. Precast piles of reinforced concrete are usual for this purpose. Multi-part piles made from concrete are also known for example from DE 44 39 115, in which at the beginning an outer and an

inner driving tube are rammed into the ground. Then, the cavities are filled with fluid concrete. Before the hardening of the concrete, the driving tubes are removed again, so that the concrete flows together in the junction region and forms an integral concrete pile with different regions.

[0013] The object of the invention is a general reduction of the dimensions and weights of the foundation of constructions, in particular wind power installations, in order to facilitate the production, the transport and the introduction into the ground, or at least to improve the cost-effectiveness.

BRIEF SUMMARY OF THE INVENTION

[0014] The foundation according to the invention for a construction has at least one pile-like device which is anchored in or on the ground and basically comprises an elongate pile element. According to the invention, it is provided that the pile-like device also has at least one reinforcement element which is constructed and disposed in such a way that between the reinforcement element and the pile element a gap is formed which is filled at least partially with at least one free-flowing filling material.

[0015] The present invention is an advantageous further development of known foundations, since the foundation according to the invention makes it possible to use the available manipulable foundation piles to produce a very rigid and durable construction which reliably transfers the forces which occur.

[0016] Furthermore, the pile-like device by which the force is transferred into the ground is divided up according to the invention, with the advantage that the necessary structure of the foundation comprises at least two elements which can be manufactured, transported and introduced into the ground individually and only then do they have to be joined to one another by a (or several different) filling or also joining material or materials.

[0017] The term "filling material" should also cover *inter alia* the function of joining the elements, since in the construction according to the invention the junctions are flexible between pure filling and pure joining and can be covered by one and the same material.

[0018] For economic reasons it is particularly advantageous that once the ram is positioned it can, if need be, drive both elements concentrically one after the other into the ground, where only one borehole in the ground is necessary and both elements can be introduced into the ground from one position.

[0019] In the case of larger constructions or in offshore wind power installations in greater depths of water, the foundation according to the invention can also have more than one pile-like device. Thus the foundation can also be a three-legged or four-legged foundation (tripod, jacket) which is known *per se,* but in which each leg can be constructed by the principle according to the invention, comprising a pile element and a reinforcement element which are joined to one another by way of a filled gap.

[0020] According to an advantageous embodiment of the invention, the reinforcement element can be constructed as an outer tube in which the pile element is disposed. According to a further advantageous embodiment, the pile element can be constructed as an inner tube which is disposed in the outer tube in such a way that the gap which substantially surrounds the inner tube is formed between them. Naturally, the opposite variant is also conceivable, namely construction of the pile element as the outer tube and the reinforcement element as the inner tube.

[0021] In the case of monopile foundations, it is known to use a tube as the monopile. As already described above, however, the monopile foundation has the disadvantage that corresponding tubes must have very large external dimensions in order to be able to ensure appropriate transfer of force. According to the present embodiment of the invention, it is possible for the wall thickness of the pile-like device to be reduced considerably with the same external dimensions since the

outer tube introduced according to the present embodiment of the invention transfers additional forces and has a reinforcing effect. Conversely, it is equally possible to reduce the outer diameter of the pile-like device with a predetermined wall thickness and thus to make it possible to produce it, transport it, or introduce it into the ground (e.g. ramming or drilling).

[0022] Since this new foundation pile according to the embodiment of the invention practically comprises two tubular piles pushed concentrically into one another, the term "duopile" has been chosen for this.

[0023] In a further advantageous embodiment of the invention, the gap between the tubes is filled with a bulk material which preferably does not damage the environment, e.g. sand or gravel, as filling material in order to avoid a relative movement of the tubes in the event of stresses occurring. Since a bulk material does not transfer tensile stress nor shearing stress, in this case the filling material serves exclusively for filling of the gap and thus for fixing of the tubes inside one another, but not for additional increase in the rigidity of the foundation pile. An advantage of this mode of construction is the dismantling of the construction after the service life of the wind power installation has expired, which is very simple in particular in the case of offshore application, as after removal of the construction based on the foundation the outer steel tube is detached and withdrawn in the region of the level of the seabed, the bulk material being simply released to remain on the seabed. In a second operation, the inner tube can be detached and withdrawn.

[0024] A further particularly advantageous embodiment of the invention provides for the use of the filling material in order to increase the rigidity of the entire pile, as according to the sandwich mode of construction which is known from the composite fiber sector the transfer of shear between two load-bearing material layers is ensured. Such a mode of construction can be achieved by the use of a high-strength cement (grout) which is known as a filling material for example from offshore technology.

[0025] In order to ensure a good joining of the filling material and the steel components and also to facilitate the transfer of the shear stress from the elements or steel tubes into the filling material, special measures may be necessary.

[0026] An embodiment of the invention provides, for example, for the construction of annular accumulations of material on the inner face of the outer tube as well as the outer face of the inner tube (so-called shear keys). This can be achieved, for example, by welding on steel bands or particularly economically only by build-up welding.

[0027] In a particularly advantageous embodiment of the invention, in order to improve the connection between filling material, tube fins extending in the longitudinal direction are applied to the outer face of the inner tube. In a complementary fashion, fins extending in the longitudinal direction and directed inwards are likewise attached to the inner face of the outer tube. In this case the arrangement of the fins is chosen in a sensible manner so that in the assembled state fins of the inner tube and the outer tube always alternate along the circumference.

[0028] Furthermore, this arrangement has the crucial advantage that at least three of the fins can be used in order to center the tubes in one another during the assembly operation, the height of the fins being tailored to the inner or outer diameter respectively of the appertaining second tube.

[0029] For further improvement of the connection between filling material and tube it may be sensible to provide openings (holes) in the rib-like components. This provision also ensures a uniform distribution of the filling material during the filling operation.

[0030] In the case of particularly hard ground, it may happen that the longitudinal fins would not withstand the stresses of the ramming process. In this case, a further

embodiment of the invention provides that at least three spacers are introduced from above into the gap with the aid of a fixing means (cable, rod or the like). The spacers can be made, for example, from plastic material, metal material or also wood. Depending upon the length of the tubes it may be necessary to introduce spacers at different positions (relative to the longitudinal direction of the piles).

[0031] The connection of the foundation pile to the rest of the construction preferably takes place by a concrete bond (grouted joint). Advantageously, it may be provided that the diameter of a substantially tubular junction piece is chosen so that it can be pushed into the gap between the inner and outer tubes. After alignment of the junction piece, this can then be connected by means of the concrete bond (grouted joint) to the inner and outer tubes, preferably in one operation.

[0032] The junction piece is preferably also equipped with the means explained above for increasing the transfer of shear between the junction piece and the filling material.

[0033] As an alternative, the junction with the rest of the construction can also be produced, for example, by means of flange or clip connections.

[0034] All the said components of the invention are of high economical benefit in particular, but not exclusively, in offshore constructions.

[0035] The invention relates not only to the foundation according to the invention but also to a method for erecting such a foundation.

[0036] For this purpose, it is provided that in a first operation either the pile-like device or the reinforcement element is introduced into the ground first according to choice. In a second operation, the element which is complementary to the first step is then introduced. As required, a complete or partial filling of the gap can now take place.

[0037] In a next operation, the junction piece is then installed which, if both elements are constructed, for example, as tubes disposed inside one another, can in principle be pushed into the inner tube, but in technical terms it is much more sensible to push it externally over the outer tube or even more advantageously to push it between the outer and the inner tubes. In a further operation, the gap(s) between the tube(s) and the junction piece is (are) then filled with a filling material. In a preferred embodiment in which the junction tube is pushed into the gap between the outer and inner tubes, the filling of the two gaps can take place jointly or also in succession (in two part-steps). It may also be sensible to arrange for the filling material in the gap to the inner tube to begin or end in a region other than in the gap to the outer tube. In this way the change in rigidity is reduced at the junction of the pile-like device with the junction piece.

[0038] In a preferred embodiment of the invention the method includes, in addition to the filling of the gap(s) to the junction piece, at least partial filing of the space between the inner and outer tubes with a filling material or also with different filling materials. This filling takes place most advantageously, but not necessarily, between step two and step three of the method described above.

[0039] The permanent sealing of the gap between the foundation pile and the junction piece preferably takes place using a permanently resilient material in a last operation.

[0040] The economical introduction of the "duopile" foundation is preferably carried out using the ramming method so long as the nature of the ground allows for this. Other methods (e.g. drilling) can also be used.

[0041] The method according to the invention is particularly practical for use in offshore constructions, since the logistical requirements there, particularly also with regard to the necessary machines for introducing the piles into the ground, can be met economically.

[0042] The invention also relates to a method of dismantling a foundation according to the invention, which is advantageous particularly when the gap between the inner tube and the outer tube has been substantially filled with a free-flowing filling material which is preferably not damaging to the environment.

[0043] After the construction and preferably also the junction piece have been dismantled, then the dismantling of the foundation takes place. For this purpose, in a first step, for example, the outer tube is detached approximately in the region of the level of the seabed, for example, using known flame-cutting processes suitable for underwater use. Depending upon the requirements of the official building authorization, in the region of the level of the seabed can mean slightly below the seabed (so that first of all excavation work or flushing out has to be carried out) or also up to a few meters below the seabed, where the detachment is to be carried out most simply using the available equipment.

[0044] In a second step, the outer tube is then withdrawn so that the filling material escapes downwards onto the seabed. In particular, in the case of a sand or gravel type of filling material which is not damaging to the environment, this filling material can remain on the seabed. In a third step the inner tube is then detached in the region of the level of the seabed and withdrawn (possibly after renewed excavation work or flushing out).

[0045] Since the foundation according to the invention can be used particularly advantageously in the field of wind power use, a wind power installation with a foundation according to the invention is an explicit part of the present invention.

[0046] The invention is explained in greater detail below for an offshore wind power installation with reference to three embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

[0047] Figure 1 shows a section through the foundation according to the invention;

[0048] Figure 2 shows a section through the foundation according to a second embodiment of the invention;

[0049] Figure 3 shows a section through the foundation according to a third embodiment of the invention;

[0050] Figure 4 shows a section through the foundation according to a fourth embodiment of the invention;

[0051] Figure 5 shows a horizontal cross section through an inner tube and outer tube of a fifth embodiment of the invention.

DETAILED DESCRIPTION OF THE INVENTION

[0052] Two different embodiments A1 and A2 of the invention, which in reality are usually of rotationally symmetrical design, are shown to the left and to the right of the vertical dash-dot line of symmetry. However, in the case of wind power installations which are exposed to high winds or high waves, for economic reasons, it may also be sensible to use different filling material over the circumference of the pile according to the prevailing direction of the high winds or high waves (e.g. inexpensive gravel in the secondary loading direction and high-grade filling material, e.g. grout, in the main loading direction).

[0053] An inner tube 1 and an outer tube 2 are introduced into the seabed (M). The junction piece 3, which is provided at the upper end with a conventional screw flange as connection to the rest of the construction 8, is pushed into the gap between the inner tube 1 and the outer tube 2.

[0054] In the embodiment A1, on the right-hand side only, the region of the concrete bond to the junction piece is filed with the filling material 6, and for this reason seals 4 to the inner tube 1 and the outer tube 2 to attached to the lower end of the junction piece 3 on both sides. Such seals 4 can for example be rubber seals, also known in the prior art as "grout seals".

[0055] In order to avoid a marked change in rigidity in the structure which is structurally unfavourable it may be sensible to dispose one of the two seals 4, e.g. the inner one, somewhat further down so that the junction is less abrupt. The same applies to the upper level of the filling. Here too, for the stated reasons, it may be sensible, for example, to fill the inner gap to a lower height than the outer one.

[0056] During the assembly operation the junction piece 3 is supported and aligned on the inner tube 1 with the aid of supporting brackets 5. In principle the supporting brackets can also be supported externally on the outer tube 2, but for reasons of protection against corrosion it makes more sense to attach them on the inner face. After the introduction of the filling material the remaining gap between the junction piece 3 and the outer tube 2 is sealed in a sensible manner with a permanently resilient material 7.

[0057] The embodiment A2 (on the left-hand side) shows the means 9 for improvement of the connection between the filling material 6 and the inner tube 1, the outer tube 2 and the junction piece 3, wherein the means are mounted both on the inner tube and outer tube 2 and also on the junction piece 3 and in this example are of annular design.

[0058] If due to the means for increasing the transfer of shear, a construction of the seals 4 shown in the embodiment A1 is not possible, the space between the inner tube 1 and the outer tube 2 can be filled to approximately below the junction piece with inexpensive filling material 10a (e.g. sand or gravel) which preferably is not damaging to the environment. Only then is the high-grade (and relatively expensive) filling material 10b for the concrete bonding introduced.

[0059] Furthermore, in the embodiment A2 a different filling height 14, 15 of the upper level of the concrete filling is shown in order to avoid the marked changes in rigidity described above.

[0060] However, depending upon the requirements of the location of the construction it is also possible as an alternative, as stated above, to provide the filling material as a supporting component of the entire foundation pile (depending upon the type of introduction to the level of the seabed or also to the lower end of the duopile). In this case the lower inexpensive filling material 10a is emitted, and the entire space is filled with the high-grade filling material.

[0061] However, in further embodiments according to the invention, the high-grade filling material can also be introduced only locally where the loading level is particularly high (e.g. directly above the fixing on the seabed or in the junction region with the junction piece, or also differentially depending upon the main loading direction).

[0062] In Figures 2, 3 and 4, by way of example three embodiments are illustrated for the arrangement of the outer and inner tubes as well as the junction piece and also for the local introduction of the high-grade filling material into the space between the outer and inner tubes or junction piece respectively.

[0063] In a completely sectional partial view Figure 2 shows an inner tube 21 which is disposed in an outer tube 22. A junction piece 23 is disposed in the space between the inner tube 21 and the outer tube 22. In the illustrated embodiment, the connection point between the tubes 21 22 and the junction piece 23 is below the surface of the water W. This is practical particularly with regard to use of material which is appropriate to the stress, since as indicated above the maximum bending stress in a pile foundation is frequently situated on the surface of the seabed (somewhat below the seabed in the case of soft ground).

[0064] Since the bending moment present decreases again between the seabed M and the surface of the water W it is also provided that the outer tube 22 of the duopile is of significantly longer construction than the inner tube 21. The outer tube 22 is rammed in so deep that the centre thereof lies at the level of the maximum bending moment. The significantly shorter inner tube 21 is then rammed centrally into the outer tube 22. The junction piece 23 is likewise pushed relatively deep into the space between the outer tube 22 and the inner tube 21, in fact to such a depth that it extends into the region of the maximum bending moment. In this case if need be the seabed should be removed between the two tubes, e.g. with a suction apparatus (suction dredger). Thus in the region of maximum stresses three tubes lie inside one another, which are then stepped in a manner appropriate to the stress first of all to two tubes and then only one supporting tube.

[0065] However, for the case where the costs for the suction (depending upon the nature of the ground in the individual case) are too high, the arrangement of the concrete bond between the seabed M and the surface of the water W is very advantageous.

[0066] In such a case, for example according to the embodiment shown in Figure 3 an outer tube 32 can be rammed very much deeper into the seabed than an inner tube 31. A junction piece 33 is pushed so far into the space that a sufficient connection region is achieved between the junction piece 33 and the outer tube 32 or the inner tube 31 respectively. Due to the stepping of the tubes 31, 32 a material use which is appropriate to the stress is achieved which is adapted to the trend of the bending moment line. For reasons of costs, the filling material is introduced in such a way that a concrete bond 30b is provided only between the regions of the junction piece 33 and outer tube 32 as well as the junction piece 33 and inner tube 31. The rest of the space substantially between the outer tube 32 and the inner tube 31 is filled with a free-flowing and more cost-effective filling material 30a. The concrete bond 30b between the inner tube 31 and the junction piece 33 is limited by backfilling of, for example, gravel to the length which is necessary for reasons of strength.

[0067] Figure 4 shows a further embodiment of the arrangement of an outer tube 42, an inner tube 41 and a junction piece 43 relative to one another as well as a local introduction of different filing material. The arrangement corresponds substantially to the arrangement shown in Figure 2 with the difference that the junction piece does not extend to the maximum bending moment but already ends above it. This offers the advantage that extra seabed does not have to be sucked up, so that costs can be saved. Furthermore the inner tube 41 is rammed deeper into the ground than the outer pile.

[0068] The stepping of the arrangements of the inner tube and the outer tube can be varied as a function of different tube parameters (e.g. mass, length and diameter) as well as the available ramming apparatus in order to combine an optimal strength with a simple installation. Therefore the embodiments shown only represent examples of a large number of advantageous variants.

[0069] Figure 5 shows a further embodiment of the invention. For better connection of the filling material to the tubes both the inner tube 51 and the outer tube 52 are provided with fins 61. In order to ensure the centring of the tubes 51, 52 during the introduction into the ground centring fins 62 are also provided.

[0070] In order to improve the connection to the filling material the fins 61, 62 can be provided with openings. They can be chamfered at the lower end in order to simplify the introduction into the ground.